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Subject: Required Improvements to the Navy Groundwater Flow Models to Achieve Regulatory Acceptance

On May 10, the regulatory agencies (EPA & DOH)) provided to the Navy comments, observations and deficiencies of their suite of groundwater flow models (GWFMs) delivered in its March 2020 Report (Rev 00). As they presently stand, the GWFM are not reliable to inform regulatory decision nor form the basis of contaminant fate and transport evaluations as required in the Administrative Order on Consent (AOC, 2015). There are two sets of required improvements to achieve regulatory approval so that the GWFMs may inform some aspects of our groundwater protection decisions. One is conceptual and qualitative, where matters of approach and model framework should be improved. The second is a series of quantitative measures that the groundwater models must achieve to better reflect area data, including pump test well responses, geochemistry and transient groundwater elevations (among others). These two categories overlap to some degree, but distinguishing between them is useful to constrain our next review of the Navy's updated models. This memo will not redevelop the various deficiencies in the Navy's GWFMs discussed on May 10, 2021, but will rather focus only on these two categories of required improvement.

After the updates below are implemented by the Navy, the Agencies expect that there will be one or two key GWFMs that best reflect area data and conditions (e.g., a base-case model). The multi-model approach used by the Navy team should lead toward hydrogeologic conclusions about likely conditions, possible conditions, and key uncertainties between competing conceptualizations. Ideally, there would be a "base case" model that best represents area data and hydrogeology that can then be used to investigate potential conditions that may present specific aquifer risk implications, such as fast-track contaminant pathways and the network of geologic features underlying those pathways. If a base-case cannot be defined, then the conditions leading to that outcome need to be clearly identified, along with the data collection and/or testing proposals to resolve those uncertainties. As noted in the AOC, the collective updates to the GWFMs need to substantially refine our understanding of groundwater flow paths, rates and the underlying hydrogeologic conditions controlling those. That last aspect, the underlying hydrogeologic conditions, being paramount to understanding risk and risk mitigation measures. Last, the major GWFM changes required need to be presented to the Agencies for concurrence prior to implementation. This step, although offered by the Agencies, was absent in the Navy's multi-model approach and the end-product was much different than envisioned by the Agencies following the Navy's proposal of that approach in August 2019.

CONCEPTUAL CHANGES

The Agencies have noted the critical importance of transient (time dependent) conditions to a variety of model predictions, such as flow behavior, response to pumping at various locations, future transport evaluations and others. While the steady-state modeling approaches are useful for interim calibration and other aspects, they are not useful for most of our aquifer protection decisions. The primary work product of interest is transient simulations and their match to existing data (groundwater elevations, gradients at different times, and geochemistry, among others). Ultimately, risk decisions will be based on the linkage to transient aspects of fuel migration, dissolved-phase migration, possible mitigation responses and other factors. As noted in the quantitative requirements, the Navy's GWFMs must reasonably match transient groundwater elevations during periods of pumping stresses (and non-pumping recovery). The Navy's GWFM report (March, 2020) appears to superimpose drawdown on measured groundwater elevations to produce an apparently good match, but the transient verification models themselves do not appear to do so. The offset between actual model predictions and field measurements is part of the same issue that was evident in the prior groundwater models (refs) that the Navy's GWFMs were intended to improve. The Navy's GWFMs did not improve those matches to transient groundwater elevations and must do so in future work as part of the suite of required improvements. At a minimum, the Navy GWFMs must more reasonably match transient groundwater elevations, gradients, geochemical distributions and other available data to be considered a useful refinement of past modeling efforts.

The Agencies' subject matter experts (SMEs) collectively observed that the geologic framework of the Navy's GWFMs is generally implausible, particularly in the area beneath and in the vicinity of Red Hill Ridge. In that area of interest (Figure 1), the actual geologic complexity is muted by the equivalent porous media (EPM) approach taken in the Navy's GWFMs. The SMEs will accept more generalized hydrogeologic conditions outside that area of interest, but enhanced interpretive methods will be necessary to create more realistic geologic renderings in the key area of interest (Figure 1). As shown by Matt Tonkin (May 10, 2021), the Agencies require that the Navy use its existing 3-D geologic model to geostatistically extend those lithologic conditions into the aquifer zone and regional area of interest. An example of the Navy's 3-D geologic model was shown in its CSM on Figure 5.11 and supporting Figures 5.2 – 5.10 (Navy CSM, Rev 01, 2019). The extrapolation method selected by the Navy should either utilize the sequential indicator simulation (ISIM) approach shown by Dr. Tonkin, or another equally robust and verified technique. The particulars of that geostatistical method should be provided for Agency review prior to its implementation. Following general agreement on the details of geologic extrapolation, the Navy's technical team should expect to update the Agencies on their progress. That would include lithologic spatial interpolations, and resulting 3-D geologic renderings to attain concurrence with those conceptualizations before they are incorporated into updated numerical GWFMs.

As part of the geologic rendering updates above, the Navy's GWFMs also need to be reconstructed with a layered model systematic, instead of high variability thickness changes in individual layers. This will facilitate changes to hydrogeologic elements and parameters, such as hydraulic conductivity, porosity, boundary behavior and others. In other words, a more conventional model layering regime may reduce some of the quantification challenges of the Navy's GWFMs.

Model parameter ranges need to be consistent with those used in prior modeling work, or where varied, a specific technical justification for that change be provided. A particular emphasis on the linkage between certain parameters and their effect on transient drawdown and other effects needs to be considered. For instance, the hydraulic diffusivity controls the transient aspects of drawdown and groundwater capture. So, factors like hydraulic conductivity, porosity, specific yield and storativity need to correspond to the transient calibrations and be considered in terms of whether their net effect enhances of diminishes potential groundwater capture from Red Hill Shaft. Transient groundwater capture is one potential element under consideration as a containment option in the case of future releases that threaten the aquifer. The Agencies emphasize that transient groundwater capture is only one element of a much more complex set of considerations regarding the most appropriate and robust release mitigation measures.

After reframing the geologic distributions in the models, the models then need to evaluate differing inflow and outflow boundaries (and their 3-D implementation) to its simulations results to better align with field-measured groundwater elevations and geochemical indicators. A geochemical mixing model approach, as shown by Robert Whittier (DOH, May 10, 2021), should be used to evaluate the groundwater flow pathways and behavior in the key areas of interest (Figure 1). In those evaluations, a ranking matrix should be developed that shows where the interaction between the boundaries and the hydrogeologic framework produce results that are more reflective of the area data (geology, groundwater elevations and geochemistry). This will help to rank more viable models against those that are less likely representative of actual conditions and how each may present conservative (worst-case) or non-conservative aspects of the range of outcomes. Again, the Agencies emphasize that a base-case model be presented as the basis for comparison against other realizations. If there is no GWFM that reasonably reflects the ranges of observed conditions in the Red Hill vicinity, then modeling will not likely be a reliable method for the groundwater protection decisions required.

QUANTITATIVE REQUIREMENTS

The following list of quantitative requirements must be attained to provide adequate model reliability for regulatory decision-making and communication with our public stakeholders. As noted above, most of the quantitative requirements pertain to transient conditions and are linked to the model calibration and parameterization process. As above, the focus is again on the key area of interest (Figure 1).

1. The GWFM updates need to match transient groundwater elevations and measured gradients in the key area of interest within 0.1-ft differential between measured and modeled results. Given measured groundwater gradients of 10^{-5} to 10^{-4} ft/ft, this still represents a substantial relative potential error, but one that is within the realm of measurement reliability. This requirement is for the direct model output and not superposition of modeled drawdown onto measured elevation data.

2. The model calibration needs to more discretely refine its time-stepping sequence to better reflect the pumping and non-pumping schedules used in the Navy's GWFM report. In other words, it needs to provide a better representation of that transient drawdown response.
3. The updated base-case GWFM needs to reflect the apparent variability in aquifer stress responses that appear to show monitoring well response groupings, as provided in the Agencies' May 10 comments to the Navy. The Navy's groundwater flow models must reflect and explain, in a hydrogeologic framing, these data observations. This is critical since the underlying hydrogeologic conditions are presumed to have risk/transport and mitigation implications.
4. Based on the statistics of the geologic model extrapolation, provide an evaluation of the applicability of an EPM approach at the scale of discrete releases at the tank farm and provide peer-reviewed literature that supports the evaluation methods. Given both vapor and sub-tank lithologic sampling results, that scale is likely on the order of tens of feet or less.
5. Provide a standard sensitivity and uncertainty analysis, linked to transient model calibrations, regarding the effect of key parameter ranges on modeling results, particularly as those affect estimates of capture and implications to the future contaminant transport evaluations.
6. Provide transient groundwater elevation differential maps for the end of each transient time step showing modeled versus measured groundwater elevations. Where groundwater capture is indicated by the GWFMs, validate that the field data also show that same capture with a vector gradient analysis at key capture locations, particularly on the distal edges of the modeled capture zone. As noted in our review, the Agencies will generally favor field data over modeled results when and if the two diverge.
7. Provide quantitative geochemical groundwater mixing evaluations and the degree of consistency with measured observations using chloride as the primary indicator. Augment with other geochemical constituents to refine the mixing scenarios as needed to make the models more consistent with this set of observations. Geochemical mixing should be a component of the calibration metrics of the groundwater flow modeling.

At key junctures of the improvements specified above, the Navy should expect their technical team to update both the Agencies and the public stakeholders through the Groundwater Modeling Working Group Forum. General input and concurrence from all involved parties will help ensure the final modeling products meet the decision-making objectives to achieve demonstrated aquifer protection.